2000 CALFED Science Conference
Session Notes

Fish Facilities And Fish Screening

Session Chairs: John Andrew and Daniel Odenweller
Session Notetaker: Marianne Kirkland

Estimating Population Level Effects on Fish for Environmental Requirements Affecting Delta Water Project Operations, or, 'Exports and Fish' – William J. Miller, Consulting Engineer.

Point: Relationships believed by some to describe the influence of various factors on targeted fish populations indicate that flow-related measures are inefficient and expensive ways to increase many of those populations. Implement other restoration measures instead.

Presentation: Delta water export restriction to benefit fish is a contentious issue. In fact, a small industry has grown up around it, complete with lawsuits against CALFED for its Record of Decision (ROD). Recent investigations show that export curtailment may not even make a difference for fish.

There are several types of environmental requirements. They take the form of export curtailments at State and Federal export facilities, minimum river flows into the Delta, Maximum salinity limitations ("X2"), and restrictions on Delta Cross Channel gates. When open, the gates pass clean water to the central Delta, and in-migrating adult salmon up the Sacramento River. When closed, the gates help keep out-migrating juvenile salmon.

Population level estimates are important to determine the relative importance of environmental actions, i.e. 'What *fraction* of fish (especially salmon) are affected?' Without population level estimates, it is difficult to assess factors' significance or inform decision-making regarding costs, and resources are likely to be misallocated. In engineering, it is often necessary to make assumptions, with pre-determined bias, to make important deductions. This approach was used.

The author's approach was to set aside disputes over fish/requirement relationships, to assume no density dependence, to assume requirements apply over the biologically critical periods, and to find the slope of the line describing abundance or survival as a function of an individual Delta water project requirement. The slope of the line shows how much of an operational change is needed to cause a unit change in fish abundance.

Results for an assortment of fish and operational measures were presented in tabular form. The first table showed the amount of operational adjustment projected to cause a one percent population increase for each category of fish, where a relationship was believed to exist. The second table showed percent direct mortality of species and/or evolutionarily significant units (ESUs) at export pumps to express direct 'take' from export pumping in the context of population size. The third table showed the cost per one percent increase in fish populations for non-flow measures such as barrier removal, gunderboom implementation, the Shasta Temperature Control Device (TCD), harvest management, and gravel placement. Costs per unit population increase were ten to one hundred times lower than costs for flow measures.

The main two results stressed were that the amount of water required for a one percent population increase is 50,000-1,800,000 acre-feet, at a cost of approximately $5,000,000-180,000,000, and that direct mortality of salmon at export pumps is negligible. Suggested management measures were to:

- Close the Delta Cross Channel gates when Sacramento River salmon are out-migrating
- Place the barrier at the Head of Old River (HOR) when San Joaquin River salmon are out-migrating,
- Curtail exports to reduce salvage *only* if effects on water supply and other species are not significant
- Curtail exports to prevent extreme incidents of relative salvage focusing on adult delta smelt
- Increase Delta Outflow only if other effects are not significant
- Implement the Environmental Water Account (EWA) if it can be established, but remember the water won't make much difference
- Sell EWA water and spend the money on more effective actions such as upstream "no brainers" and innovative harvest reductions

Questions:

Q: What assumptions did you make regarding indirect impacts of export pumping?
A: The Revised Newman-Rice Analysis that deals with the survival and mortality of fish entering the Delta, from Mossdale and traveling to Chipps Island. Newman-Rice made no differentiation between direct and indirect mortality; there was just an equation expressing survival as a function of export rate, Delta Cross-Channel Gate operation, etc. BJ took the partial differential of each variable, hence his reference to 'slope' in the presentation.

Note: During the presentation, tabular results were shown in small print overhead, but neither paper nor report to which the author referred was made available.

Review of Factors Affecting Fish Salvage at South Delta Pumping Plants – Thomas Cannon, Foster Wheeler Environmental Corp.

Point: Fish salvage at Project facilities has been proportional to export rate, outflow, net San Joaquin River flows, seasonal life history factors, and population abundance and distribution. Recent and planned protective actions that have the effect of limiting high spring and early summer exports likely limit salvage events.

Presentation: Based on data taken from the Interagency Ecological Program (IEP) Internet site, salvage has been proportional to export rate, outflow, net San Joaquin River flows, seasonal life history factors, and population abundance and distribution. Historical high salvage events would not occur today because of the protective actions that are already being taken.

Delta smelt salvage events have occurred in wet and dry years, with high export rates (8,000-14,000 cfs). Salvage of adults occurs in winter, and then tends to drop, perhaps because of spawning migration. In a typical 1987-1988 salvage event, exports were 10,000 cfs, and Qwest was negative. Salvage of young delta smelt tends to occur in spring. They are of salvageable size from May to July, when exports are high, there is low or dropping delta Outflow, and Qwest is negative. Salvage of young can be high even at low export rates. It is proportional to the fall midwater trawl index, and not proportional to the summer townet index. Many graphs were shown to help visualize the correspondence of delta smelt salvage with Delta Outflow, Exports, and Qwest.

Chinook salmon salvage is correlated with outflow pulses, decreasing outflow, and increasing exports. Winter salvage may be high in very wet years. In very dry years salvage occurs when Qwest is negative.

Splittail salvage is correlated with decreasing outflow, and increasing exports. Adults are salvaged from January to April. Adult events are correlated to spawning migrations, Qwest, and exports. Young tend to be salvaged on the declining hydrograph, when they come out of the floodplain.

Steelhead patterns are similar. Winter-spring outflow pulses seem to drive the salvage of steelhead. During February of each year salvage occurs regardless of hydrology. Steelhead is stocked in-river by hatcheries.

Striped bass are salvaged primarily from late spring to early summer, in November after the first pulse in Delta outflow, and in early winter (Jan/Feb) when Qwest is negative.

In addition to environmental operation measures that are already taken, suggested operational measures include:

- Avoid increasing exports when delta outflow is falling sharply
- Avoid sharp changes in exports, outflow, and Qwest
- Open DCC gates in May or June
- Shift to Tracy pumping rather than State pumping in dry years
- Avoid high exports under low outflows
- Increase delta outflow in March and April of drier years
- Confine high export to late summer, early fall, late winter
- Eliminate big gulp operations at Clifton Court Forebay
- Study temperature, Spring-neap tides, and weather further.

Questions:

Q: What magnitude of outflow is needed?
A: It depends on the season. Adaptive management is appropriate here.

Fish Entrainment Monitoring for the Old River Pumping Station Using and 'On-Stream' Screen – Jerry Morinaka, Department of Fish and Game.

Point: Monitoring is conducted behind the screen at Contra Costa's Old River Pumping Plant as a conditions of operation. Results to date indicate entrainment of a variety of small fish, but delta smelt entrainment is minimal.

Presentation: Entrainment monitoring has been conducted at Los Vaqueros, an "on stream" station pumping from Old River, south of Highway 4, near Clifton Court Forebay. Entrainment results presented are for monitoring conducted behind the screen from March 1998 to June 2000.

The facility is a state of the art positive barrier screen belonging to the Contra Costa Water District. Water flows from the diversion to Contra Costa Canal and/or Los Vaqueros Reservoir. A floating boom protects the facility, which has 75 feet of inclined flat plate stainless steel wedgewire screen, with 3/32 inch spacing and vertical bar orientation. The diversion can divert up to 250 cfs, using five pumps each rated at 50 cfs. At 250 cfs, the designed approach velocity is 0.33 ft/sec, and at 150 cfs it is 0.2 ft/sec. Sweeping velocities at the site are provided by a combination of tidal ebb and flow, and draft from the SWP intake to Clifton Court. Since the diversion's completion in 1997, the water district has continued testing velocities.

The facility has automatic cleaning, and is unmanned, run from a control office in Antioch. Atlas polar mechanical rakes with Teflon pads and nylon brushes clean the screen front. Debris is pulled up, dumped to a trough, and pushed by automatic arm to a dumpster. There have been some problems with debris hanging up in the rake. Panels are also cleaned annually with high-pressure jet spray, to remove debris, sponge, and anthropods from the back side of the screen. From 1997 to 1998 pumping through the facility was intermittent, allowing much sponge and anthropod growth, and accumulation of detritus.

The long-term monitoring program for this screen was designed by Jones and Stokes, and is being carried out by DFG. It is required by the CESA MOU that monitoring be conducted to demonstrate effectiveness for delta smelt and salmon to determine "take" of delta smelt and winter-run Chinook salmon. A large sieve-net is fished behind the screen three times a week from January 1 to June 30, and once a week the rest of the year. Monitoring varies between crepuscular, day, and night times. The net is supported by a frame and filters an entire bay of diversion. The net is 14 feet by 15 feet at the opening, and 45 feet long, composed of nylon mesh with a soft cod end. The net slides down tracks for installation, and a gantry crane lifts it for removal. Once removed, a rail system is used to transport the net between bays.

From March 1998 to June 2000, 19 species were captured, three native, and sixteen nonnative. One delta smelt, and two splittail were captured, but no salmon of any run/race were captured. The size of fish captured ranged from 8 mm to 308 mm FL. It is thought that the larger fish had grown to size behind the screens after passing through the screen as juveniles, were resident previously, or had entered while screens were removed for cleaning. Fish smaller than 25 mm were assumed to have been entrained through the screens. Most fish were about half that size. The prevalent species captured varied considerably by year. In 1998, threadfin shad comprised 82% of the catch. In 1999, the catch contained 75% prickly sculpin, and 11% striped bass.

Monitoring results are preliminary, but it appears that delta smelt take is minimal, and salmon are safeguarded by the 3/32-inch screen. Sweeping velocities are influenced largely by SWP and CVP intakes. It is hoped that the basic knowledge gained from this facility will help in developing new facilities.

Questions:

Q: Is there any channel sampling to determine fish species composition?
A: Yes, but the smaller version of the net used did not catch many fish. Delta smelt did not appear to be present in the area.

Q: Have cameras been utilized to detect predation?
A: No.

Q: So fish get scraped with debris?
A: There does not appear to be plant build-up.

Q: Is there much sponge growth?
A: Sponge does grow, but not as severely when the diversion is in operation.

Q: How many pumps are usually used?
A: In summer all five pumps are usually working.

Biological Evaluations of the Georgiana Slough Experimental Acoustical Fish Barrier, Phases I-IV During 1993-1996 – Kevan Urquhart, Department of Fish and Game

Point: Results from five years of April-June monitoring fish movement in the presence of experimental acoustical guides at Georgiana Slough were mixed, and will not be continued. However, one must be honest in reporting results, and not highlight only the most favorable. Experimental technology costs may be cheap*er*, but not cheap!

Presentation: The Georgiana Slough experimental acoustical fish barrier is located just downstream of the Delta Cross Channel. A behavioral device was tested because a rock barrier or screen was infeasible at this site due to tidal and flow fluctuations. Sixteen to twenty-two percent of Sacramento River flow passes through Georgiana Slough. Depth of flow varies between fifteen and thirty feet. Velocity is variable, with reverse flows at times. There is a need for upstream fish migrations. Reductions in incidental take could preclude export pump shutoffs.

For the study, about twenty transducers were suspended by an anchored buoy. Kodiak trawls trapped wild and marked salmon downstream of acoustics, in both the Sacramento River and Georgiana Slough. The relative passage down Georgiana Slough and the Sacramento River was examined.

In Phase One, velocities were mostly positive. Two types of netting were tried, and Kodiak trawls were used because they worked. Hansen Environmental performed Mantel-Haenszel Chi squared analysis to test effectiveness.

In Phase Two, the tidal range was not as great. The sound field did not extend into Georgiana Slough. The acoustics were operated on a two-day on, two day off schedule. Guidance efficiency weighted for nonzero pairs was 57.2%. From 832 observations, with a probability <0.001, daytime acoustical operation made a significant difference. Night operation did not make a significant difference in passage. Ebb tide was also significant, and two mark-recapture studies suggested measurable efficiency of 35-?%.

During Phase III, flows were too high to install, so only fall data were gathered. No delays were found in migration. Sound did not harm eggs, young, etc.

During Phase IV, guidance efficiency was not significantly different from zero.

Experimental costs varied annually, for a total of $2,921,000. Operation and maintenance costs varied ($150 k-$250 k- $500 k) depending on hardware losses, etc.

This experiment showed one year of successful guidance, but in the context of overall performance, it was discontinued. Other issues included:

- Guidance was only good at medium flows, for some Q and v combinations,
- A new marina in the area did not like the sound produced
- There is a potential for negative guidance depending on flows
- Quantification of costs and benefits

Several conclusions were offered. Statistically robust experiments are expensive, but less intensive efforts cannot prove out hypotheses. Environmental impacts must be demonstrated to agencies. It is not enough to look only at the best-case scenario; one must honestly show all results. Experimental technology costs may be cheap*er*, but not cheap!

Long-Term Trends in Fish Salvage at the SWP and CVP Facilities: Differences Between Facilities – Robert Fujimura, Department of Fish and Game.

Point: Despite the close proximity of the SWP and CVP intakes, trends in species salvage at SWP and CVP are dissimilar. Do not rely on a single data set to represent the system.

Presentation: Personal, as well as professional interest in fish collection data led Mr. Fujimura to explore salvage data. He compared annual Indices at SWP and CVP, and examined long-term trends. Frequently daily salvage at the two sites does not correlate well; at red light levels for endangered species, there is much speculation as to the predictive strength of indices. The many nonlisted species are not usually investigated.

SWP and CVP fish facilities are described for background on the data sets compared. The CVP Tracy Fish Collection Facility was built in 1957, and has been in continuous operation ever since. The maximum capacity is 4,600 cfs. The intake diverts directly from Old River, and it is screened by a simple louver system. There is a single secondary channel with secondary louvers. Fish are collected in collection tanks, and then transferred to tanker trucks for remote Delta release. The SWP Skinner Fish Protective Facility was built in 1968, with a complex louver array and multiple secondaries to screen the SWP pumping plant's larger export capacity. The SWP Banks Pumping Plant diverts from Clifton Court Forebay. Pumping tends to be concentrated to off-peak (night, weekend) hours to minimize electricity costs.

From the Department of Fish and Game ftp site, data from 1979 through 1999 was downloaded for thirteen fish species. A salvage index for total fish collected, and a species occurrence index were used in analysis. They were plotted as timeseries, analyzed by linear regression and correlation analysis, and compared by relative percent difference. Of the thirteen species, six were native (splittail, prickly sculpin, steelhead rainbow trout, lampreys, white sturgeon, and Sacramento sucker) and seven introduced (striped bass, white catfish, channel catfish, largemouth bass, common carp, bigscale longperch, and golden shiner). Eight were resident, and five were anadromous.

An Annual Salvage Index was derived normalizing the number of fish salvaged by the total water exported for the year. The Annual Occurrence Index is the percent of the days that fish were present in salvage. Relative Percent Difference was used to compare the relative number and frequency of occurrence of species at the SWP and CVP using the previous two indices. It was calculated by the subtracting CVP index from the SWP index, multiplying by 200%, and dividing that quantity by the sum of SWP and CVP indices. Positive values reflected higher likelihood in SWP salvage, and negative values reflected higher likelihood in CVP salvage.

Annual Salvage Indices from state and federal facilities were compared. For the purposes of this comparison, strong correlation was defined to exist for r greater than or equal to 0.866, moderate correlation for r values between 0.866 and 0.707, weak correlation for r values less than 0.707, and no correlation where r was zero or negative. Salvage of only one species displayed strong correlation, salvage of common carp (r = 0.964). Salvage of three species showed moderate positive correlation: white catfish, steelhead, and white sturgeon. Other species showed weak or no correlation.

For Occurrence Indices, largemouth bass, gold shiner, and channel catfish exhibited strong correlation. Salvage of splittail, prickly sculpin, and common carp was moderately correlated between CVP and SWP facilities. There was weak or no correlation for the other seven species.

Relative percent differences showed whether species were more often present (occurrence indices) or more plentiful (salvage indices) at one location or another. The *average* relative percent difference in salvage indices was positive for prickly sculpin, longperch, sturgeon, suckers, striped bass, and steelhead, and channel catfish. In terms of averages values, these fish were relatively more plentiful in SWP salvage than CVP salvage. However, for all species, the mean +/- two standard deviations spanned both positive and negative relative difference values. Relative percent differences in salvage index (mean +/- two standard deviations) were exclusively of one sign only for carp. Carp was clearly more plentiful in CVP salvage. Values for white catfish were *almost* exclusively negative; they were almost always more common in CVP salvage.

Based on the mean relative percent difference in occurrence indices, sturgeon, longperch, prickly sculpin, steelhead, lampreys, splittail, largemouth bass, channel catfish, and striped bass were more frequently present in salvage samples. As with abundance indices, two standard deviations about the mean spanned a broad range of relative percent difference values that included both positive and negative differences. Only the two-standard-deviations of striped bass and white catfish were limited to less than one hundred percent variability, and still these envelopes spanned positive and negative values.

After assessing salvage variability between the SWP and CVP sites, Mr. Fujimura addressed the question ‘Did salvage indices increase or decrease over the last 21 years?’ Linear regression analysis showed there was a possible trend (here defined as r^2 less than 0.5 but not zero) in salvage indices of several fish. Salvage of Sacramento sucker (at CVP only), prickly sculpin, and largemouth bass may be on the rise, while salvage of white catfish and white sturgeon may be decreasing.

Linear regression of occurrence indices shows a definite increasing trend (here defined as r^2 greater than or equal to 0.5) in occurrence of five species: prickly sculpin, largemouth bass, bigscale longperch, golden shiner, and channel catfish (SWP only). A possible increasing trend was apparent at CVP only, for Sacramento sucker, steelhead, white catfish, lampreys, and channel catfish.

In conclusion, the Salvage Index showed no or poor correlation between facilities. Annual differences can vary greatly. Most species showed weak or no trends in salvage index. Higher correlation values were found for occurrence indices, for which definite increasing trends were observed. Alternative salvage indicators may be helpful. Detailed seasonal and life stage analysis is needed, as are entrainment studies behind CCF gates. Salvage data should be analyzed on a site-specific basis. The inherent variation is probably due to several biological, physical, and/or operational factors.

The Hudson River Aquatic Filter Barrier (AFB) Test and Proposed AFB Deployment Test at Southern Energy Delta, LLC. (SED) Contra Costa Power Plant, Antioch, CA – Steven Gallo, Southern Energy California.

Point: We have great hopes for aquatic filter barrier technology called 'Gunderboom' to serve well in the west Sacramento-San Joaquin Delta, as it has been in New York, and intend to test it. Matted polyethylene fabric is suspended by buoys and anchored at the bottom to provide a large surface area that can screen intake water with velocities ten times slower than legally required.

Presentation: An Aquatic Filter Barrier (AFB), marketed as 'Gunderboom', has been installed at Lovett Generating Station, NY. The plant draws water from Tomkins Cove, on the Hudson River, 42 miles North of New York City. It operates on the left bank of the river looking north, in a tidally influenced estuary environment. The AFB strains water for Unit 3, while intakes for Unit 4 and Unit 5 just have trashracks, and a 3/8-inch screen. Unit 3 generates 63 MW, and extracts 42,000GPM (94cfs). Its AFB is a floating billet system with a radius of 4,000 feet. There is a shipping channel on the far side of the river.

Bill Gunderson first engineered the Gunderboom for applications in Alaska. The technology was noticed there, and requested to be adapted for application in New York. Five hundred feet of matted polyethylene fabric has been joined in a two-layer, reinforced panel with cells seven feet wide. The panels extend the full water depth and are cleaned by sequenced airburst. Original applications had a single layer of fabric, and no cleaning mechanism. In the course of development, manual valves have been made automatic. The filter barrier is suspended from a boom flotation. The top and the bottom of the barrier are attached by polyline and chains to anchors outside the enclosure formed. Other polylines and chains connect the bottom of the AFB to additional anchors on the interior of the enclosure. A buoy marks the exterior anchors for monitoring and boat safety.

Velocity meters may be used to sequence airbursts with respect to sweeping velocity. The barrier is designed to have 0.02-0.03 ft/sec approach velocity. Common fish in the area include bay anchovy... Striped bass are native there.

An application of the Gunderboom AFB is planned in the Sacramento-San Joaquin Delta of California. It will be for an intake of 305kGPM (680 cfs). The AFB will extend 350 feet offshore, and have a length of 1700 ft, depth of 25 feet, and area of 26,000 square feet. It will extend into the river by about one tenth the river's width at that location. The matted fabric will be have regularly spaced two mm holes for additional porosity. As in the New York application, the approach velocity will be 0.02-0.03 ft/sec, an order of magnitude lower than required by regulations.

Questions:

Q: Do you have any idea of the river velocities there?

A: Three to four feet per second is common.

Q: How will the AFB withstand large debris that comes down the SJR?
A: Strain gauges on anchor lines will be used to detect any openings or snags. The Lovett plant has already survived a hurricane, trees, and other impact loadings.

Q: What is the design life of the AFB?
A: We do not know.

Q: What will be the frequency of airburst?
A: It is hourly back east. We will adjust it as needed for the Antioch.

Q: Are you doing anything to mitigate for heat in discharge water?
A: There will be no change in discharge, though there may be some increased mixing.

Q: Is there play in the anchor lines?
A: Yes.

Q: Are you aware of peat moss loads in the area?
A: We will be experimenting with long-term efficiency.

A New Modular Screen System for Protecting Fish at Water Intakes –Kent Zammit, Electronic Power Research Institute (EPRI) for Edward Taft

Point: High-velocity screens such as the Modular Inclined Screen are successful new alternatives for protecting fish at water intakes.

Presentation: The Modular Inclined Screen operates at velocities between 2 and 10 feet/sec. A bar rack protects the intake to the screen, which pivots vertically for self-cleaning. In normal operating conditions, the two-mm wedgewire screen is inclined upward, flushing fish upward through a bypass, and passing most water through the screen. Stop logs are placed downstream of the screen for dewatering. The screen design is under US Patent 5,385,428.

EPRI laboratory testing was conducted at the Alden Research Laboratory. Dye tests show uniform flow through the screen. Three velocity probes were used. An air-injection port was used to inject fish into the inflow. Atlantic salmon, chinook salmon, coho salmon, channel catfish, rainbow trout fry and juveniles, brown trout, walleye, bluegill, and blueback herring/American shad were tested. They mean length of the species tested ranged from 6.7 to 1.9 inches. Net survival of nearly 100%. Generally survival was 99%+ at up to 6 ft/sec entrance velocities. A few survival rates have been in the low nineties, and the lowest survival rate, ~80% survival of juvenile alosids, occurred at 10 ft/sec, the highest intake velocity tested. Injury is negligible for most species. Impingement was reduced by blocking flow through screen along transition walls downstream of the ice sluice gate in the test.

Debris effects were also tested. Low levels of debris did not affect fish passage. Impingement and injury increased for most species when head loss increased by more than 0.2 feet. Larger fish such as Atlantic salmon smolts were not affected at head loss up to 0.5 feet.

In addition to laboratory studies, field studies at Green Island Hydropower Plant on the Hudson River near New York City have been conducted with rainbow trout juveniles, largemouth/smallmouth bass, golden shiners, bluegill, yellow perch, and blueback herring. In the field evaluation at Green Island, net passage survival was lower at higher speed for blueback herring, but otherwise generally similar. Yellow perch also survived less well at higher speeds.

Another high-velocity fish screen called the Eicher screen has been tested at Puntledge River near Elwah. Nearly 100% of the pacific salmon tested survived at a channel velocity of 6 ft/sec.

These high-velocity screens are simple to design, biologically effective with the variety of species tested, cost effective, and available for hydro, steam, electricity, and irrigation applications. They may be employed at significant cost-savings. The MIS costs $1,200-3,700/cfs. The Eicher costs $1,400-4,500/cfs. In contrast, angled fixed screens and angled drum screens are running $2,000-8,000cfs, and wedgewire screens may cost $10,000-30,000/cfs.

Questions:

Q: When you introduce fish, are they well mixed in the water column?
A: Ned is not here, so I cannot answer.

Q: Were videos taken during testing?
A: Yes.

Q: Is the profile bar oriented perpendicular to flow?
A: I don’t know.

Q: If the screen angle is 20-30 degrees, are velocities lower?
Q: If not using an injection well, fish would have to survive bypass.

Q: What are bypass flow and velocity?
A: Don’t know for tests, but in hydropower applications, we do have head available to return bypassed fish.

Biological and Hydraulic Performance of Two Unconventional, High Sweeping Velocity, Self-Cleaning Fish Screen Technologies – James W. Buell, Buell & Associates, Inc.

Point: High-velocity fish screens are proving successful at safely separating fish in test applications, even though they do not meet the low-velocity design criteria approved by regulatory agencies.

Presentation: Two unconventional, high sweeping velocity fish screen technologies have performed superbly in hydraulic and biological evaluations. Full scale installations proved to be self cleaning and biologically effective. Neither design meets generally accepted fish protection criteria.

A Coanda screen has been tested on a 127 cfs East Fork [Hood River, OR] Irrigation District diversion. The Coanda screen has an overflow weir design. It employs fine horizontal profile bar screen, with flow of 120 cfs. There is 0.5 -1.0 mm clear space between bars of the screen, and fish are exposed to the screen for less than one second. No power is required, and the screen has a small footprint, so the screen is relatively inexpensive. It passes up to 4 cfs per foot of crest. The test screen passes 120 cfs through 60 ft of screen. Its bypass has 10 cfs of flow. Two to three feet of head are consumed by the Coanda screen.

Though the Coanda screen does not meet current codes, it passes fish successfully in trials. Fish injury and survival studies have been conducted with steelhead from 30 to 50 mm FL, chinook fry (35-40 mm FL), and steelhead smolts. Five fifty-two-fish trials and three fifty-two-fish controls were conducted for each size-group of fish. The only fish injury measured was loss of 0.5% of scales on tested fish, the same as control fish. Probability equals 0.902 that fish were not damaged by passage over the screen. Factors that affect efficiency include: clear space between profile bars, “attack” velocity, profile bar angle, and civil works.

Farmer’s Irrigation District (Hood River, OR) constructed a full-scale (75 cfs) high sweeping velocity flat plate screen in their irrigation ditch as a prototype for planned permanent installation. The screen is of horizontal submerged punch plate, without moving parts. While the sweeping velocity is high, approach velocities are low (0.1-0.2 ft/sec). Fish exposure time is short, only 20 seconds. The screen requires non-turbulent canal hydraulics. Permeability control is tricky. The screen passed 73 cfs over 55 feet of width, with three cfs going to a fish bypass.

During testing, some fish were lost in cracks between the screen and civil structure. The simple solution is to eliminate the cracks! There was no injury of any kind to fish subjected to the screen, with 92% probability by the Wilcoxon signed rank test. There was minor latent mortality: two adults in two studies died during holding. One upstream hotspot needs correction, and this may be fixed by tapering the lip. The rule of thumb is > 10:1 sweeping: approach velocity.

The Coanda screen is more effective but consumes head and does not meet agency criteria. Screen can be as fine as 0.5 mm. The other satisfies agency criteria, consumes no head, and has a smaller footprint. It is not appropriate for tidal areas. The cost is $1-2,000 k/cfs

Questions:

Q: The Coanda screen lost fish because of an imperfect seal?
A: Yes, and some fish even went upstream before passing the screen!

Fish Passage Success with Archimedes Lifts and a Helical Pump on the Sacramento River – Charles Liston, USBR.

Point: Background on testing of the 'fish friendly pumps' at Red Bluff Diversion Dam, and some results, are presented. The juvenile hatchery reared Chinook salmon tested passed downstream more readily at night than during the day. No pump-passage effects of Archimedes lifts, and minimal (2.5%) pump-passage effects of helical pumps were found in 96-hour mortality. Direct mortality indicated low but significant pump-passage effects in control, Archimedes, and helical groups.

Presentation: Red Bluff Diversion Dam was constructed in 1967, with fish ladders for upstream passage and other facilities for downstream passage. The inefficient original louver system and bypass for juveniles were later replaced with drum screens. Unfortunately, pike minnows congregated below the dam, consuming outmigrant salmonids and other small fish. There are about thirty-one fish species in the area, but the conservation focus has been on Chinook salmon.

The movement to return to run-of-river conditions for fish led to initiation of a mid-1980s pilot study to look into pumping diversion water to avoid backing up water at Red Bluff Diversion Dam. From 1997 – 1999 experiments were conducted to compare archimedes lifts and helical pump mortalities and debilitating injuries in juvenile, hatchery reared Chinook salmon. Multiple pump passage trials have been conducted, and the results are presented.

Chinook were passed through two pumps simultaneously. In these paired trials, fish experienced similar temperature, dissolved oxygen, turbidity, and debris load covering the ranges of seasonal variation for which the pumping plant was designed. Thirty-two Chinook were used in each Chinook sample group. Treatment samples were placed in pump intakes, and control samples in pump outfalls. Fish recovered in holding tanks after passing through a fish bypass. The net treatment effect was determined by subtracting control group results from treatment results.

Time in travel varied. At night eighty-five percent of fish were recovered within ten minutes, while during the day only fifty-three were recovered in that time. During the day, more fish held out upstream of screening facility holding tanks longer than the tanks were tended to recover fish.

Pump-passage effects of Archimedes pumps were not detected through 96-hour mortality, sub-lethal injuries. There was no evidence in the data that a particular type(s) of injury was related to pump-passage. De-scaling differences were not significantly different in Archimedes-Archimedes trials either. Helical pump tests did show a 2.5% pump-passage effect in 96-hour mortality.

Direct moralities were tallied when juveniles were collected from holding tanks, and delayed mortalities were tallied among individuals that were held for 96-hour post-trial observation. There was a pump-passage effect for direct mortality for test and control samples used with both types of pumps. The pump-passage effect was significant for the Arch lifts ($P = 0.02$), and highly significant for the internal helical pump (<0.01). However, the two types of pumps differed in the magnitude of pump-passage effects; the pump-passage effect of the internal helical pump was higher. The difference in %-direct mortality was highly significant for treatment samples used with the two types of pumps ($P = 0.001$), and the difference between control samples used with the two types of pumps was not ($P = 0.44$). No pump-passage effect was detected for delayed mortality with either type of pump. No significant pump-passage effect was obtained for total 96-hour mortality (sum of % direct and % delayed mortality for each trial, MRPP techniques) for Archimedes lifts.

Questions:

Q: Why not design a pumping plant on the river at Red Bluff?
A: Twenty million dollars were already committed to the drum screens.

Q: Was an increase in mortality shown without external injuries?
A: We do no know the causes of fish deaths. There may be some internal turbulence we are unaware of. Bruising was noted, but there was next to no difference between test and control groups.

Q: Is there some engineering advantage to one pump over the other?
A: The helical pump has smaller civil works and is less expensive.

Q: Are there plans to put a pump in the fourth bay of the facility?
A: Yes, we plan to put a new pump in the third bay, and the helical in the fourth bay.

Travel Time and Condition of Juvenile Chinook Salmon Passed Through Red Bluff Research Pumping Plant – Sandra Borthwick, USBR.

Point: Additional Red Bluff Research Pumping Plant results are presented. Pump passage was a slight source of mortality, higher for the helical than the Archimedes. Mortality and injury were also slight at the screening facility. The plunge pool was also somewhat injurious. Little or no mortality was associated with the underground bypasses. Total 96 hour mortality (including mortality due to sampling gear and post-capture handling), ranged from two to nearly four percent on average. Pulsing flows were ineffective at passing fish stalled between vertical v-screens, but effective at flushing fish from the drum screen bypass to the river outlet.

Presentation: Red Bluff Diversion Dam backs up the Sacramento River for Tehama-Colusa and Corning diversions. Drum screens keep fish out of the diverted water, and bypass pipes pass fish downstream. Red Bluff Research Pumping Plant has bypass pipes that connect with the main ones for the diversion, and pass fish to the in-channel outfall.

Three main objectives of study at Red Bluff Research Pumping Plant are: to determine how long it takes juvenile salmon to pass through the plant, and where delays occur; to determine mortality, injury, and de-scaling of juvenile Chinook salmon passing through the plant; and to determine the effectiveness of "pulsed" flows at flushing fish through.

The results of passage and survival experiments are presented. For passage experiments, hatchery-reared fall Chinook (54 to 62 mm) were used in whole-plant trials to determine passage time from pump intakes to bypass outfall, and segment trials to identify where passage delays occur. Fifty fish were released per site, and fish recovery was checked at 0.5, 1,1.5, 2, 12, 24, 36, and 48 hours, as well as after a pulse flow of about 160 cfs at velocity of 8 ft/sec. Four whole-plant and four segment trials were conducted with Archimedes and helical pumps, two at sunrise and two at sunset.

In whole plant trials, passage time differed significantly between day and night released groups. Twenty-five to thirty-five percent of fish were not recovered after 48 hours. Pulsing flows were effective at moving fish out of the bypass pipes. There was no significant difference in salmon recovery by pump. ($P > 0.05$).

Segment trials isolated components of whole plant trails. Pump passage did not affect travel time. Fish delayed between vertical v-screens, and pulsing flows created by turning pumps off and on again were ineffective at hastening fish. There was no delay in the plunge pool. Fish delayed most at the drum screen bypass to the river outlet. Pulsing flows created by opening weir gates were effective in flushing the fish out.

Survival experiments included sixteen night trials using 42-69 mm Chinook. Fifty fish were released into the pump intake and outfall of both pump types, and captured in a live box at the outfall in the river. Fish were counted after one hour, and then after a ten minute pulsed flow. Direct mortality, delayed mortality, de-scaling, and injury were assessed after 96 hours.

Approximately forty percent of released fish were captured after one hour, regardless of pump type, treatment, or control. Approximately eighty-five percent were recaptured post-pulse under all conditions.

Total 96 hour mortality (including mortality due to sampling gear and post-capture handling), ranged from two to nearly four percent on average. For the Archimedes lift, 2.4 percent was due to bypass exposure, with an additional 1.4 percent mortality in the test groups due to pump exposure specifically. For the helical pump, an average of 2.0 percent mortality was incurred by the control group that experienced only the bypass, and mortality was 1.9 percent higher in the test groups. Pulsing flows did not significantly increase mortality, and were effective at moving fish from the bypass.

De-scaling and injury analysis showed that the mean percent of body surface de-scaled or abraded was less than 1.5 percent. Mean percent was used as a measure because some fish used were so young that their scales were not well developed. The mean percent of fish injured was 1.3% to 7.5%. Injuries to skin and fins were most common. There were no significant differences between sample times, or between treatment and control groups for either pump. There were no significant differences between pump types for treatment and control groups.

In summary, pump passage was a slight source of mortality, higher for the helical than the Archimedes. The mortality and injury were also slight at the screening facility. The plunge pool was also somewhat injurious. Little or no mortality was associated with the underground bypasses.

Questions:

Q: What were the flow and velocity in the 5-foot bypass?
A: The flow was about 160 cfs, and the velocity about 8 feet/sec.

Q: Night vs. day trials?
A: After two nights you would think the fish would come out. Fish did not stall as greatly in segmented trials.

Fish Treadmill Facility for Testing Fish Performance Near Fish Screens/ A Hydraulic Apparatus for Studying Fish Behavior Near Screens – Zhiqiang Chen, UC Davis

Point: The Fish Treadmill has been designed for close control of a wide range of conditions in the two foot wide swim channel where fish are tested.

Presentation: The objectives were to create flow conditions in the fish treadmill similar to that in a long fish screen channel for various fish species: to make the flow field as uniform as possible, and to make the water surface as smooth as possible. A round vertical screen was used to approximate a long fish screen. The inner diameter of the fish swim channel is nine feet, and the channel itself is two feet wide. The porous outer wall of the swim channel rotates to allow flow to enter the swim channel while creating a flow vector at an angle to the inner, stationary fish screen where water exits. Fish are subjected to an approach velocity component perpendicular to the inner screen, and a tangential sweeping velocity across it. The hydraulics of a smaller scale model were tested before the present larger model was constructed.

The fish treadmill facility is supplied with well water, and has an underground water sump storage system. A water heating and cooling system maintains water temperature +- 1 C for experimental purposes. A fifty horsepower pump lifts water through the water recirculation system. Water is piped from the sump through the side wall to the lower region of the treadmill. It wells up in the very outer annulus of the fish treadmill, then flows inward and down over a circular weir. Baffles straighten the flow and paddles accelerate it tangentially. Water flows through the outer rotating screen and the inner stationary fish screen that define the fish channel. A concrete ramp sloping toward the stationary inner fish screen helps to keep the water surface level. After passing through the stationary inner fish screen, water flows down through the center of the treadmill back to the underground sump. A flow meter allows experimenters to monitor the flow into the treadmill. Treadmill flow can be reduced by opening a bypass valve to reject some flow directly back to the underground water sump. Observation platforms are provided in and above the fish treadmill. A head tank feeds the fish holding facility.

Sweeping velocity, approach velocity, and temperature are variables in experiments. Sweeping velocity is controlled by the rotating speed of the outer rotating screen. Approach velocity is a function of the incoming flow rate and water depths in the swimming channel. Temperature is controlled by the heating and cooling system.

Detailed descriptions of flow fields in the swimming channel were created from point measurements, and are used in fish behavior analysis. Fish behavior analysis assesses fishes' location relative to the inner screen, velocity past the screen, rheotaxis (orientation with or against flow), swimming velocity, and kinematics (swimming gaits). Ten flow regimes were identified for testing. They combine approach velocity ranging of 0.00, 0.20, 0.33, or 0.50 ft/sec, with sweeping velocities of 0.00, 1.00, or 2.00 ft/sec.

Approach, sweeping, and vertical velocity components are checked at three cross-sections of the fish swim channel. Color graphics depict the variability that exists in cross sections of the flow even with careful design.

Different flow regimes can be simulated to test various delta fish species in the fish treadmill. A reasonably uniform flow distribution has been achieved in the swimming channel of the fish treadmill. Water temperature and water quality in the fish treadmill can be controlled in both winter and summer.

Questions:

Q: Do you try different materials on the outside screen?
A: No. The outer screen is just a barrier, and only one inner screen has been used so far, vertical wedgewire.

Performance and Behavior or Juvenile Chinook Salmon near a Simulated Fish Screen – Joseph Cech Jr., U.C. Davis.

Point: Experiments with several species of Delta fish are planned for ten combinations of approach and sweeping velocity, water temperatures of 12 C or 19 C, and day and night timing and lighting. Performance, behavior, and physiology are measured. Experiments with smolt-sized and parr-sized Chinook salmon are complete.

Approach velocity, time, and temperature have little effect on screen contact rate. Seventy-five percent made screen contact with tail only. Contacts and injuries were more severe in dark/at night. Screen contact frequency was not correlated with injury indices.

Smolt-sized juveniles' screen passage was more rapid than that of parr-sized juveniles at intermediate sweeping flows, but similar at high sweeping flows. Therefore, the strategy to minimize effects (e.g., including presumed vulnerability to predatory fish) of fish screens would be to divert water during daytime periods of high sweeping flows.

Presentation: There are 2,224 diversions in the Delta, mostly 11 to 20 inches in diameter. Winter run salmon are endangered, and spring run threatened. Fish screens should safely separate fish from diverted water. The fish treadmill used in studies at UC Davis hydraulics lab is similar to the treadmill used by pioneers Odenweller, Brown, and Kano. Results from it have implications for Skinner Fish Facility, and for new fish screens as well. Experiments have been performed for ten combinations of approach and sweeping velocity, water temperatures of 12 C or 19 C, and day and night timing and lighting.

In each salmon study run, twenty juvenile chinook salmon are placed in the swimway, and their performance, behavior, and physiology are measured. Parr-sized salmon were four to six cm long. Performance is quantified by screen contact, impingement, and entrainment. Behavior is measured in terms of channel location occupied, velocity past screen, and actual swimming velocity. Aspects of physiology are recorded by stress indicators, injury, and immediate and delayed mortality.

Salmon tend to contact the screen only with their tails. Seventy-five percent made screen contact with tail only. There is no apparent relationship of contact rate to approach velocity. There is little time or temperature effect. Contacts are sometimes more common at the beginning of a run. During the day, sweeping velocity is important, but approach velocity does not appear to be significant. Salmon contacted the screen more frequently at night, and sweeping velocity effects were obscured. Daytime injuries tended to occur early in experiments. Based on health assessment injury index, night injuries tended to be worse, and more temporally distributed. In ninety-two experiments, each with twenty fish each, only five died, all at night. Graphed with respect to resultant flow, the injury index scatter indicates little relationship of flow magnitude to salmon injury.

Main conclusions: During the day, screen contacts were less frequent when sweeping flows were present. Screen contacts were more frequent during dark/night conditions than during light/day conditions. Screen contact frequency was not correlated with injury indices. Smolt-sized juveniles' screen passage was more rapid than that of parr-sized juveniles at intermediate sweeping flows, but similar at high sweeping flows. Therefore, the strategy to minimize effects (e.g., including presumed vulnerability to predatory fish) of fish screens would be to divert water during daytime periods of high sweeping flows.

Questions:

Q: Your observations were made in clear water. Have you considered green or brown water? I assume it would shift the results toward the dark data.
A: We have not, but we are planning to do some debris loading. We have considered a dye, but not found one without other effects. We cannot use bentonite because of the treadmill configuration.

Q: Have you tried low light to mimic crepuscular light conditions?
A: No, not yet, but it is a good suggestion for future study.

Development of Fish Screen Criteria Using the Fish Treadmill – Christina Swanson, UC Davis.

Point: Screen criteria might best be directed toward minimizing screen exposure duration. Fish passage past a screen depends on sweeping velocity, the swimming velocity of the fish, and fish orientation relative to flow (rheotaxis).

Presentation: Many people and agencies collaborated and funded this project. Thank you to research assistants from the Department of Wildlife, Fish, and Conservation Biology at UC Davis, to members of the UC Davis Department of Civil and Environmental Engineering, and to DFG, DWR, USBR, and CALFED.

The fish treadmill is as has been described in earlier presentations. Currently, treadmill studies are designed to identify ways to help screening criteria be efficient and effective. Approach and sweeping flow vectors are controlled during experiments, as well as temperature, light/day vs. dark/night, and fish size (4-6 and 6-8 cm SL). Experimental measurements are made to describe fish performance, behavior, and physiology. The treadmill is versatile, and there is potential for many other types of studies.

Quantitative understanding of relationships among: flow (approach, sweeping), the screen, species, environmental conditions, fish performance, and fish behavior is thought to be important to identify factors that influence successful fish protection and passage. For example, different day/night, water temperature, and resultant flows affect the rate and severity of screen contacts, which in turn affect delta smelt survival, as illustrated by several graphs. Screen contact rates directly (but weakly) relate to resultant flow velocity at night, but not during the day. Forty-eight hour mortality is directly related to contact rates; the higher the contact rate the more delta smelt die within 48 hours post-experiment. Also, the higher the flow, the higher the mortality, possibly because it matters how hard delta smelt hit the screen. These graphs illustrate relationships.

Swanson also created some graphs to illustrate the potential for experiment results to be used more directly in design and operation of fish screens. For delta smelt these graphs depicted decreasing isopleths along which combinations of approach and sweeping velocities could be expected to produce a specific level of mortality. Day and night predictions were expressed on different graphs. The daytime graph has convex isopleths. During the day, under light conditions, at 0.3 ft/sec, an average of 5-10% of the fish die regardless of how low the approach flow is. The resulting isopleths for night, dark conditions were concave and decreasing, and the percent mortalities for combinations of velocity components were higher. Under identical flow conditions, delta smelt experience greater mortality at night, but the general relationship of approach and sweeping velocities was similar.

Chinook salmon exhibited different behavior and resilience than delta smelt. Flow has a significant effect on screen contact, but screen contact does not translate into either injury or mortality. Therefore, rather than minimizing screen contacts, screen criteria might best be directed toward minimizing screen exposure duration. Fish passage past a screen depends on sweeping velocity, the swimming velocity of the fish, and fish orientation relative to flow (rheotaxis).

Chinook salmon swimming behavior is size and/or life-history-stage dependent, particularly at intermediate flows. Younger parr are more likely to swim against currents and older smolts are more likely to swim downstream. With multiple regression analysis, graphs showing the length of time for salmon to pass a 200-foot screen were produced. These isopleths were vertical lines, reflecting the primary importance of sweeping flows. During the day under light conditions, a 4-6 cm parr would take about ten minutes to pass a 200-foot screen if the sweeping flow were about 1 ft/sec. In contrast, 6-8 cm smolts would pass such a screen in about three minutes at the same sweeping velocity.

Sacramento splittail are also being studied with the treadmill. Like Chinook salmon, splittail experience frequent contact with the screen, particularly at night. Contact rates are flow dependent. But also similar to CS, that screen contact is neither injurious nor lethal. At night splittail drift with flow and therefore passage velocity, or net movement relative to the screen, is extremely predictable and roughly equal to sweeping flow. Splittail swim erratically during the day. Fish may swim upstream at velocities approaching 2 ft/sec, holding their position with next to the screen. Fish may also swim downstream, their self-propulsion, in addition to the sweeping velocity, moving them past the screen rapidly. Results are preliminary, but to date illustrate no consistent relationship between swimming behavior and flow, fish size, temperature, and duration of exposure. Therefore no predictions regarding their passage can be made at this time.

These examples have illustrated how detailed descriptions of how fish interact with flow near a fish screen could be applied to design screens and/or operate diversions to the benefit of species of concern. Experiments with the fish treadmill continue, to complete data sets for species like delta smelt, and to expand to different species and different conditions. Results have been, and will continue to be presented to resource managers in a variety of forums, with the ultimate goal of providing information useful for improving fish screens like those in the Delta.

Questions:

Q: How do your results indicate we should operate?
A: Differently depending on what fish are present.

Q: What if all kinds of fish are present?
A: Operate to the 'lowest common denominator' fish, delta smelt. They are the ones that get stuck on the screen and can't get off.

Q: Do you think the relative distance that fish have to get away from the screen in the treadmill has an effect on your results?
A: It is true that the swim channel is only two feet wide. In an experimental sense, a larger flume would be needed to test the channel width effects. However, fish positioning in the channel has been measured relative to the screen. Some fish stay close to the screen, and some move further away.

Q: What sizes/ages of fish (kind?) are present?
A: Juveniles and sub-adults in the summer, and maturing sub-adults and adults in winter.

Q: If you light the screen at night, will fish exhibit daylight behavior?
A: Earlier study has shown that light level is more significant than circadian effects, except for delta smelt, for which effects are additive.